Renewable and Sustainable Energy Reviews 16 (2012) 1165–1173

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Wind energy and assessment of wind energy potential in Turkey

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ARTICLE INFO

Article history:
Received 6 July 2011
Accepted 9 November 2011
Available online 8 December 2011

Keywords:
Wind energy
Wind power
Renewable energy
Wind plants

ABSTRACT

In this study, the potential of wind energy and assessment of wind energy systems in Turkey were studied. The main purpose of this study is to investigate the wind energy potential and future wind conversion systems project in Turkey. The wind energy potential of various regions was investigated; and the exploitation of the wind energy in Turkey was discussed. Various regions were analyzed taking into account the wind data measured as hourly time series in the windy locations. The wind data used in this study were taken from Electrical Power Resources Survey and Development Administration (EIEI) for the year 2010. This paper reviews the assessment of wind energy in Turkey as of the end of May 2010 including wind energy applications. Turkey's total theoretically available potential for wind power is around 131,756.40 MW and sea wind power 17,393.20 MW annually, according to TUREB (TWEA). When Turkey has 1.5 MW nominal installed wind energy capacity in 1998, then this capacity has increased to 1522.20 MW in 2010. Wind power plant with a total capacity of 1522.20 MW will be commissioned 2166.65 MW in December 2011.

Contents

1. Introduction

Renewable energy technologies such as solar, wind, biomass, geothermal, etc., become more important since there are local resources and indefinite sources of energy. While most renewable energy projects and productions are large-scale, renewable technologies are also suited to small off-grid applications, sometimes in rural and remote areas, where energy is often crucial in human development. Renewable energy is an economical power resource in many areas, especially at rural areas of the country. Some renewable energy technologies are criticised for being intermittent or unsightly, yet the renewable energy market continues to grow. Climate change concerns coupled with high oil prices, peak oil and increasing government support are driving increasing renewable energy legislation, incentives and commercialization. Thus, recently, the role of renewable resources such as wind, solar, and geothermal energy has been growing by leaps and bounds within other resources as their generating costs decrease.

Renewable energy which stems from natural sources such as sun light, wind, wave, water and geothermal heat sustains itself and does not pollute the environment. These sources offer many environmental and economical benefits in contrast to conventional energy sources. Renewable energy is derived from resources that, for all practical purposes, cannot be depleted and produce fewer pollutants. This makes renewable energy fundamentally

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doi:10.1016/j.rser.2011.11.021

different from fossil fuels and has prompted many countries, including Turkey, to promote its use through incentive and subsidy schemes. In addition, fuelled by preparations for joining the European Union and the approval of the Kyoto Protocol as an Annex I country, policy makers increasingly recognize the potential role of wind power as part of the country's future energy. Growing concern about emissions from fossil fuel generation increased government support, and higher costs for fossil fuels have helped wind power capacity in the Turkey grow substantially over the last decade [1–3].

Wind results from the fact that the earth's equatorial regions receive more solar energy than the Polar Regions, and this sets up large scale convection currents in the atmosphere. Meteorologists estimate that about 1% of the incoming solar radiation is converted to wind energy. Since the solar energy received by the earth in just ten days has energy content equal to the world's entire fossil fuel reserves, this means that the wind resource is extremely large [4].

Wind energy has many advantages, such as low cost, cleanliness, and abundance in everywhere in the world. Wind energy is also known as a renewable and environmentally friendly energy source. As known, harmful emissions released from various sources such as CO, CO_2, NOx and SOx have been causing negative effects on the atmosphere. Renewable energy sources are clean, free and inexhaustible. Wind power, for example, is a clean fuel; wind farms produce no air or water pollution because no fuel is burned [5,6]. It does not have a transportation problem and does not require a high technology to utilize the wind energy. The technology converting wind energy to mechanical and electrical energy is more economical compared to other energy conversion systems. In order to benefit from wind energy, before it must be converted into mechanical energy, then it is converted into electrical energy. Therefore, at the areas with sufficient wind densities, great economical benefits can be obtained by establishing wind energy conversion systems (WECS).

2. Obtaining energy from wind

Wind power is available from the kinetic energy of the mass of moving air. Wind electricity generation systems convert wind energy into electricity by means of wind turbines. Only towards the beginning of this century has development of high speed wind turbines for generation of electrical power been pursued. The amount of energy that wind carries increases by a factor of two as its speed increases and is proportional to the mass of air that passes through the plane of the area swept by the rotors. The power that can be obtained from wind is calculated in terms of the swept area of the wind turbine rotor, for a horizontal axis wind turbine (HAWT). The kind of engineering design based on analysis in the presently understood sense could not begin until the necessary mathematics and the engineering applications of it had been conceived. As wind power is the product of energy within a given time, the power of wind increases by a factor of three as the speed of wind increases. According to the Betz theorem, the amount of energy obtained by converting wind energy to mechanical energy is proportional to the third power of wind speed [3]. As a result, if the diameter of the rotor blades is doubled, the power increases by a factor of four. If the wind speed then doubles, power increases by a factor of eight (Eq. (1)). This means that the site for a wind machine must be chosen very carefully to ensure that the location with highest wind speed in the area is selected. In 1920, Albert Betz demonstrated in his theory of the closed stream tube that a wind turbine can only convert a maximum of 59% of the energy in wind into electricity. Current wind turbines convert up to 50% of energy in wind into electricity, thus coming very close to the theoretical limit. This optimum performance is attained when a wind turbine's rotors slow the wind down by one third [7].

$$P = \frac{1}{2} C_p \rho A V^3 \quad (1)$$

where P is the power output (W), C_p is the power coefficient that can be calculated using appropriate aerodynamic models, ρ is the air density (about 1.23 kg/m^3), A is the rotor swept area (m^2) equal to $(\pi(D^2/4))$ for a horizontal axis wind turbine whose diameter is D, and V is the wind speed (m/s).

Table 1
The scatter installed power of Turkey according to resources.

Sources	Installed power (MW)
Natural gas	12,734.8
Coal	10,196.8
Geothermal	84.7
LPG	2480.0
Wind	1100.00
Hydraulic	15,061.0
Others	1965.7
Total	43,526

3. Various energies resources in Turkey

Energy is one of Turkey's most important development priorities. Turkey is an energy importing country and domestic fossil fuels are limited, because Turkey has no large fossil fuel and natural gas reserves but the economical condition of the country is getting better, almost all of the petroleum and natural gas needed is imported. With very limited oil and gas reserves, Turkey is increasingly turning to renewable energy sources as a means to improve its energy security and curb dependence on imported gas from Russia and Iran. For these reasons, the development of the country and use of renewable energy sources and technologies are increasingly becoming vital for sustainable economic development of Turkey.

In Turkey, the electricity is mainly generated by hydraulic power plants and thermal power plants which consume coal, natural gas, fuel oil, and geothermal energy as it was shown in Table 1. Turkey possesses abundant some energy sources (like coal, hydraulic, solar, thermal, wind, biomass, etc.) while at the same time; heavy energy consumption takes place in Turkey. Turkey has no large oil and gas reserves, and the main indigenous energy resources are lignite, hydro and biomass. Currently, there are some main problems with respect to the energy condition in Turkey: a low per capita level of energy consumption, environment pollution, low efficiency of energy utilization, and small proportion of renewable energy. Accordingly, Turkey has to adopt new, long-term energy strategies to reduce the proportion of fossil fuels in primary energy consumption. Turkey has also taken another recent step which is consistent with its current long-term energy strategies by announcing that it will sign up to the Kyoto Protocol. Therefore, some key issues have become the priority of the nation, such as the adjustment of energy structure, reduction of greenhouse gas emission, reduction in environment pollution, and enhancement of energy security. By doing so, Turkey will commit to cut greenhouse gas emissions, demonstrating its commitment to clean technology. The development and use of renewable energy sources and technologies is increasingly becoming vital for the sustainable economic development of Turkey. The most significant developments in renewable production have been observed in wind, hydropower, sun and geothermal energy production. Distribution of the gross electrical energy according to sources in 2010 is shown in Table 1 [8].

As it is seen from Table 1, most of the electrical energy is produced from hydraulic power, coal and natural gas. It can be seen

that the proportion of natural gas in the electrical energy production has increased in recent years and its rate is 29% in the total installed power. Since Turkey imports almost all required natural gas, this high rate usage in producing electricity than the world is an important point to be examined economically. On the other hand, the share of coal in electricity generation is 23% in the total installed power. While electrical energy production from the wind has grown rapidly, in the Turkey, especially after Law on Utilisation of Renewable Energy Resources for Electricity Production in 2005. Wind energy, consequently, which is a renewable energy source, is also among the items that must be investigated very seriously. The present study shows that there is an important potential to use renewable energy, especially wind energy seem to be the most interesting domestic and clean energy sources for Turkey. Energy consumption is increasing parallel to the technological development in the any country.

4. Wind power potential for Turkey

This article sheds light on the possibilities of utilizing wind energy in Turkey, and it focuses on the viability of installing wind power plants locally. In the 1970s, 1980s and 1990s, petroleum shortages and increasing costs pushed the development of alternative energy sources. Increasing energy prices in the 1980s and growing interest in renewable energy sources led to their reconsideration, particularly in Turkey, although the take-up of the technology is still slow. In these years, the push came from a renewed concern for the environment in response to scientific studies indicating potential changes to the global warming if the use of fossil fuels continues to increase.

Theoretically, yearly wind potential of Turkey is very big, which is about twice as much as the current electricity consumption of country. Turkey's technical wind energy potential is 88,000 MW and its economic wind energy potential is about 10,000 MW. According to the reports of State Electrical Studies Board, wind energy potential of Turkey is estimated as around 120 billion kWh. Studies have showed that total wind energy potential of Turkey is higher than its present thermal and hydraulic energy production [9–13]. Annual average wind speed and annual average wind energy density of various regions of Turkey are shown in Table 2 at regional base. Compared to seven regions of the country, wind power densities are seemed to be higher at Marmara, Aegean and South-East Anatolia. Wind speeds are therefore higher at these three regions. The annual average wind speeds range from 2.12 m/s in the East Anatolia region to 3.29 m/s in the Marmara region. According to the data from the General Directorate of State Meteorological Studies, Turkey's annual mean wind speed is 2.58 m/s and wind power density is 25.82 W/m^2. The most attractive regions for wind energy applications are the Marmara, the southeast Anatolian and the Aegean regions. These regions are highly suitable for wind power generation, since the wind speed exceeds 3 m/s in most of these areas. Along with the mean values of the regions, some focal wind potentials within these regions are listed in Table 2 [14,15].

Table 2
Wind energy potential of Turkey over various regions.

Region	Annual average wind speed (m/s)	Annual average wind density (W/m^2)
Marmara region	3.29	51.91
Aegean region	2.65	23.47
Mediterranean region	2.45	21.36
Middle Anatolia region	2.46	20.14
Black Sea region	2.38	21.31
Eastern Anatolia region	2.12	13.19
South-eastern Anatolia region	2.69	29.33
Average	2.58	25.82

After this investigation, many places of the country were seen to have potentials suitable for wind energy systems. There have been many researches to prove that electricity can be produced by wind energy in many areas like Edirne, Istanbul, Çanakkale, Balıkesir, Bandırma, Manisa, Muğla, Aydın, Osmaniye, Antakya, Mardin, Siverek, and Sinop. The most promising places were seen as South coasts of Marmara Sea, cost of Aegean region, Mediterranean coasts, and Mardin and Siverek of South-East Anatolia.

5. Scattering of wind energy potential of Turkey

Studies on determining wind energy potentials of promising areas are gaining importance. At first stage, Wind Energy Observatories (WEO) were established in some promising places like Akhisar, Bababurnu, Bandırma, Belen, Datça, Foça, Gelibolu, Gökceada, Kocadag and Sinop and the mean values of wind speeds (m/s) were calculated at monthly base (Table 3). Measurements were generally taken at 10–30 m altitudes from the ground with an interval of 10–60 min. Therefore at the areas with sufficient wind speed and densities, great economical benefits can be obtained by establishing wind energy systems [15].

Wind speed varies throughout Turkey from season to season. Monthly mean wind speed variations throughout the year are presented in Table 3. The trends of the monthly means for the year are similar for the acquisition station. For the overall year, the mean wind speeds are above 6.46 m/s from January to December. The maximum monthly mean wind speed of 12.0 m/s arises in December, while the minimum of 6.1 m/s occurs in September for Bandırma. In Turkey, the higher heating demand also occurs from November to April, which can be grouped as the cold season. Wind speeds of some points in these areas yearly mean speed are 8.04 m/s in Bandırma, 7.41 m/s in Belen, 7.36 m/s in Gökçeada, and 7.36 and 6.8 m/s in Kocadağ and Gelibolu, respectively. Turkey has rich wind power potentials in many areas.

In Turkey, it is possible to see a few private sector companies are investing on energy production with wind power lately. Due to legal restrictions, in order to produce electricity by wind turbines,

Table 3
Monthly changes of wind speed for different regions of Turkey.

Station	J	F	M	A	M	J	J	A	S	O	N	D	Mean speed
Akhisar	5.2	6.2	2.7	2.7	4.3	5.4	8.7	9.0	5.0	7.1	5.6	8.3	5.85
Bababurnu	6.0	6.0	5.9	6.0	3.0	5.3	6.2	6.4	4.5	5.7	5.9	8.2	5.75
Bandırma	–	–	8.1	6.6	6.5	6.8	8.2	9.6	6.1	8.4	8.1	12.0	8.04
Belen	4.8	4.9	5.4	6.0	5.0	9.3	11.5	10.3	8.2	5.3	5.6	5.8	7.41
Datça	4.6	5.1	4.7	4.5	6.5	5.6	8.0	9.9	6.2	5.5	5.3	5.4	5.9
Foça	5.6	5.5	5.6	5.3	4.8	5.5	5.8	6.3	4.7	5.8	6.0	7.4	5.7
Gelibolu	7.4	6.7	8.3	6.0	5.2	5.8	5.7	7.6	5.7	7.4	7.0	9.1	6.8
Gökçeada	7.7	6.9	8.1	6.7	5.3	5.9	6.2	7.8	5.7	7.5	7.6	10.8	7.2
Kocadağ	8.0	7.7	8.0	7.0	7.0	8.6	8.6	6.5	7.2	5.3	7.1	–	7.36
Sinop	3.9	4.2	4.9	4.7	4.5	4.8	4.4	4.1	–	–	5.3	5.2	4.6

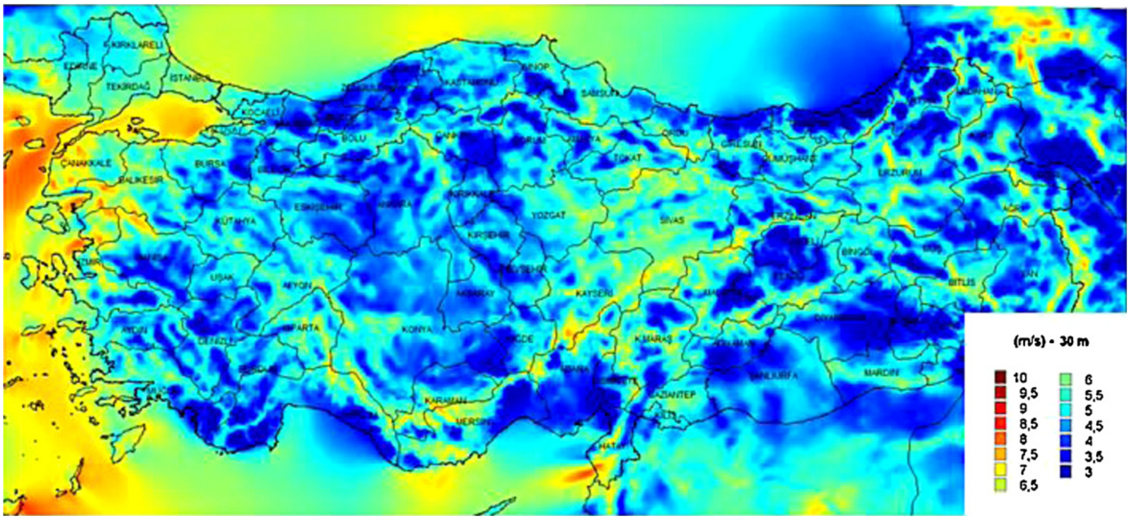


Fig. 1. Scattering of wind velocity in 30 m high.

it is necessary to get permission from the Ministry of Energy. The machinery used in WECSs is generally imported since Turkey has no industry on manufacturing these systems. At regions having high wind energy potential, supplying energy for agricultural are alike irrigating systems and domestic use in farms can be prior advantages. Output can be satisfactory since the need of energy is quite low at rural areas and the connection lines are expensive to install. Considering the simplicity and the smaller size of wind energy systems, they are economically feasible to install and run. For the areas that need small amounts of energy, energy production and supply can be overcame with smaller investment. Fig. 1 shows the wind speed scattering in 30 m high in Turkey [16].

The wind energy resources in Turkey are widely distributed at lands and coast lines. As demonstrated in Fig. 2, the wind-rich areas are mainly dispersed in north-west, west, north, and north-south Turkey, especially in the west coast (particularly the sea coast of Çanakkale and Bandırma Province) and the islands nearby. In addition, wind energy resource is also ample in South-east Mediterranean Region, eastern Antakya, northern Osmaniye, eastern Siverek and Mardin and some regions in south-west Turkey. These areas that can be technically exploited are the district where the yearly average wind energy density exceeds between 200 and 300 W/m^2.

The wind energy resources in Turkey are widely distributed at cost regions of the country. As demonstrated at the wind atlas of Turkey (Fig. 2) [17], the wind-rich areas are mainly dispersed in north, north-west, and west and especially in the south coast, and in the south-east of Turkey and the Marmara region [18–20].

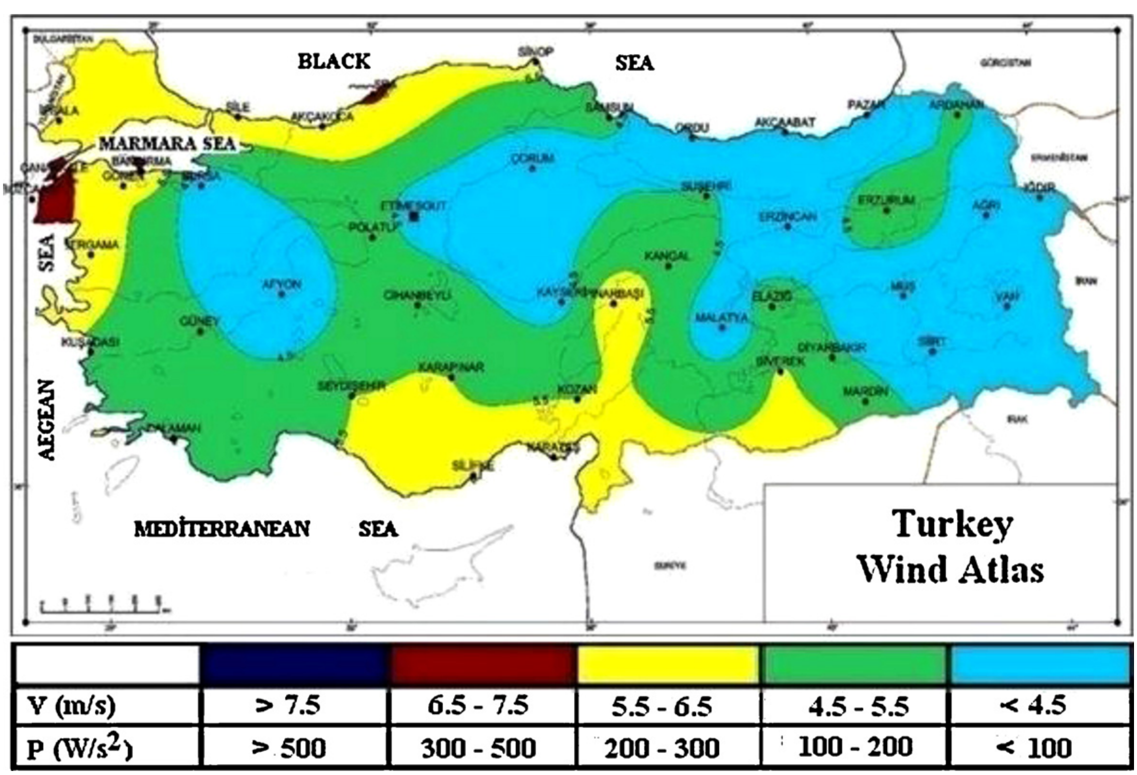


Fig. 2. Wind atlas of Turkey.

Table 4
Total of the wind potential at 50 meter in Turkey.

Wind class	Wind power (W/m²)	Wind speed (m/s)	Total area (km²)	Total potential (MW)
3	300–400	6.5–7.0	16,781.39	83,906.96
4	400–500	7.0–7.5	5851.87	29,259.36
5	500–600	7.5–8.0	2598.86	12,994.32
6	600–800	8.0–9.0	1079.98	5399.92
7	>800	>9.0	39.17	195.84
	Total		26,351.28	131,756.40

Table 5
The potential sea wind in Turkey.

Wind class	Wind power (W/m²)	Wind speed (m/s)	Total area (km²)	Total potential (MW)
3	300–400	6.5–7.0	1385.98	6929.92
4	400–500	7.0–7.5	1026.64	5133.20
5	500–600	7.5–8.0	688.96	3444.80
6	600–800	8.0–9.0	348.51	1742.56
7	>800	>9.0	28.54	142.72
	Total		3478.64	17,393.20

In addition, wind energy resource is also ample in south-eastern Siverek, south-eastern Antakya and some regions in eastern Turkey. As seen in Table 4, the area that can be technically exploited, such as district where the yearly average wind energy density exceeds 150 W/m^2, is approximately 26,351.28 km^2 [21].

According to the data observed between 1998 and 2000, the wind energy resource at 30 m height in Turkey is 4350 million kW, and the technically exploitable amount is about 297 million kW.

6. Sea coast wind in Turkey

In the coast, wind flow from sea to land in days and it flow from land to sea in nights. During the night, the direction of the wind is reversed because the land cools more quickly than water, affecting the air above it. The continental, cool air blows seawards to replace the warm air that rises from the sea surface. This outflow from land to sea constitutes the land breeze. These breezes may extend up to 50 km inland in the tropics. They may also be observed near lakes and seas. Since three sides of Turkey are surrounded by seas, Turkey has important wind energy and wind power potential especially in the Marmara region coasts, the Aegean region coasts, coasts of northern and southern Anatolia. Modern wind mills can be installed near the coasts, on the hills, and at the openings of valleys through the sea for small or medium sized power production systems.

Turkey has a land surface area of about 800,000 km^2. Turkey's geographic location has several advantages for extensive use of most of the renewable energy sources. Turkey is located between Europe and Asia and surrounded by seas at three sides. It is found the Black Sea in the north, the Marmara and the Aegean Sea on the west and the Mediterranean Sea in the South of Turkey. Turkey has a very long coast line about 8337 km. Black sea coast is 1685 km, Marmara sea coast is 2510 km, Aegean sea coast is 2600 km and Mediterranean sea coast is 1542 km, and totally they are 8337 km length [22]. The wind energy resources in Turkey are widely distributed at cost regions of the country. Moreover, in the off-shore district with a depth less than 25 m, the wind energy resource is abundant. Thus far, the total theoretic capacity and exploitable amount of off-shore wind energy resource are still under evaluation. The potential sea wind in Turkey was seen in Table 5 [23,24].

7. The status of wind energy applications in the world

After the oil crisis in 1973 and in 1980, wind energy as renewable energy gained great importance in the world's countries. During these periods, many studies were carried out in Europe and USA related to the development of wind turbines, especially Germany, Spain, US, etc. At the end of 2009, Germany (25,777 MW) was by far the largest market for wind turbines, followed by Spain (19,149 MW), Italy (4850 MW) and France (4492 MW) in Europe. Eight countries (Germany, Spain, Italy, France, the UK, Portugal, Denmark and the Netherlands) now have more than 1000 MW installed wind power. As the three pioneering countries of wind power Germany, Spain and Denmark are home to 72% of installed wind power capacity [25]. However, the use of wind turbines that convert wind energy into mechanical energy and then convert it into electrical energy was addressed in data conference held in Denmark following 1990 because of the first world oil crisis. Wind power accounts for approximately 19% of electricity use in Germany, 16% in Spain and 4% in Denmark in European countries. Installed wind power capacity in the world is seen in Table 6 [23].

Table 6
Installed wind power capacity in the world.

Country	Installed capacity
Japan	2%
Canada	2%
France	2%
Netherlands	2%
Portugal	2%
UK	3%
Italy	3%
China	3%
Denmark	4%
India	8%
Spain	16%
United State	16%
Germany	28%
Rest of the world	9%

The United States is an important growth area and installed U.S. wind power capacity reached 25,170 MW at the end of 2008. The use of wind energy in the world has exhibited a large increase in recent years. In 1996, worldwide installed wind power capacity was 6100 MW. At the end of 2000, the installed wind energy capacity was about 3 times greater than in 1996 and reached 17,400 MW [15]. There was 59,091 MW of installed wind power in world in January 2005, according to the European Wind Energy Association (EWEA), which is targeted to reach to between 70,000 and 75,000 MW by 2010. Furthermore, according to reports of the EWEA, this number is expected to increase to 280,000 MW in 2020. Total installed wind power in the world between 1996 and 2009 has been seen in Fig. 3 [26].

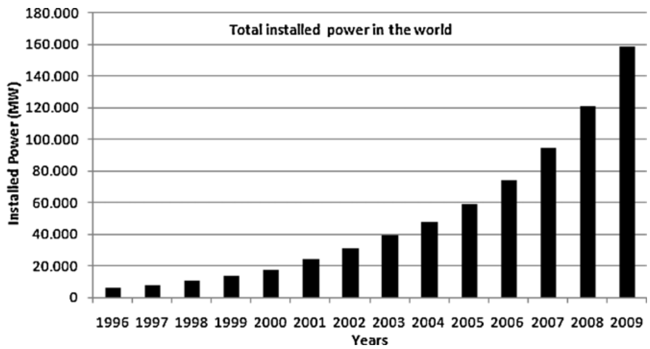


Fig. 3. Total installed wind power plants in the world.

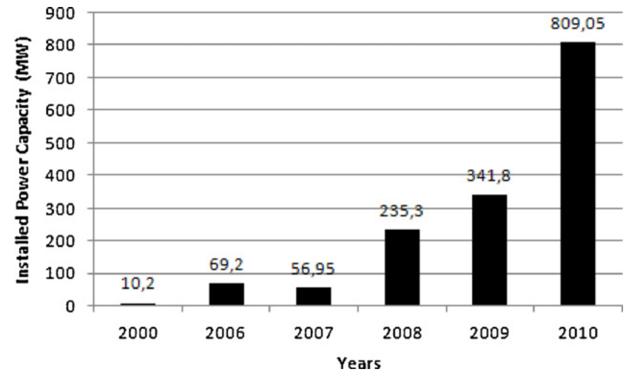


Fig. 4. Total installed capacity of wind power in Turkey.

As can be seen in Fig. 3, in January 2009, the largest installed capacity in World was 131,437 MW, and at the end of 2009 installed capacity was 157,899 MW. In 2010, the installed wind power capacity was 203,500 MW (GWEC). With this increase in wind energy conversion, a large portion of World's energy requirements will be provided by wind, and therefore, millions of tons of CO_2 generation are estimated to be avoided. Climate change concerns coupled with high oil prices, peak oil and increasing government support are driving increasing renewable energy legislation, incentives and commercialization. New government spending, regulation, and policies should help the industry weather the 2009 economic crisis better than many other sectors.

8. The current status of wind energy applications in Turkey

Determining of wind energy potential for the selected sites in Turkey is made by investigating detailed data of the wind characteristics, such as speed, continuity, availability and direction. In the last decade, a lot of studies related to the wind characteristics and wind power potential have been made in Turkey [27–31]. Wind energy application in Turkey began from 2000s, and both the relative industry and technology developed in the same period. When it comes to Turkey's situation pertaining to wind energy exploitation, it can be seen that Turkey is rather unsuccessful in using its potential before 1990s. From the beginning of the 21st century, the significant role of renewable energy in the national energy strategy has been identified, especially by the promulgation of "The Renewable Energy Law of Turkey", which introduced tariff support for electricity produced by renewable sources, in 2005. After this law, the unit capacity of wind turbine has grown from kilowatt to multi-megawatt and wind energy utilization in Turkey is progressing rapidly. Since 2006, the Turkish government has made a series of policies to promote wind energy application. As a result, wind power industry and the construction of wind farms underwent rapid development, which further accelerated technology development, in 2010 (Fig. 4). As being a developing country, it is very important for Turkey to keep a balance between country economy, energy and environment during the modernization process of the country. Assessment of renewable energy source in the electricity generation is an important fact for Turkey in terms of both security of energy supply and environmental concerns.

Turkey's wind energy installed capacity was 10.2 MW the end of 2000. It became 20.1 MW at the end of 2005. There were five wind power plants having total 50.1 MW installed capacity and 54 wind turbines. This installed capacity has increased 79.4 MW in 2006 and then increased 136.35 MW in 2007. The biggest wind energy power plant (BARES wind energy plant) with 20 wind turbines and 30 MW installed power, in Turkey was built at Bandırma-Balıkesir in 2006. Total wind power installed in Turkey, wind energy generating capacity, was 371.65 MW at the end of 2008. Up to the end of 2009, 26 wind farms have been built in the main land with a total installed capacity of 713.45 MW, in which the increment in 2008 was 371.65 MW. The yearly installed capacity increased 52% in 2009, and the increase in total installed capacity was about 399% in 1010, as shown in Fig. 2. At present, there are 44 wind power plants having total 855.05 MW installed capacity and 822 wind turbines. The biggest present wind energy power plant (GE Wind Energy Plant) with 54 wind turbines and 95 MW installed power, in Turkey was built at Osmaniye in 2010. It is expected that the installed capacity in Turkey will have reached 2166.45 MW by the end of 2011[31,16].

9. The wind energy status of Turkey

Turkey is one of the windiest places in Europe and Asia; and can reduce its dependence on fossil fuels very quickly when using its domestic renewable potentials even more quickly than other European countries and at very low costs, much lower than when continuing the fossil or nuclear approach. In order to make a reasonable long-term development plan, the Turkish Government has started the national wind resource investigation and evaluation in 2005. The Government has adopted "Law on Utilisation of Renewable Energy Resources for Electricity Production". Further, the Law on the Use of Renewable Energy Sources for Electricity Generation Purposes, that is Renewable Energy Law, has been adopted on May 10, 2005 [32]. The main purpose of the Renewable Energy Law was to encourage and expand the use of renewable energy sources, such as wind, solar, geothermal and biomass, for the purpose of electricity generation. The Renewable Energy Law stated only few insufficient incentives for renewables and set forth some additional land use principles. Therefore, the Renewable Energy Law also failed to bring the long awaited dynamism to the renewable energy industry.

10. Current status of wind energy usage in Turkey

Till the end of 2006, more than 86 wind turbines under 79.10 MW have been produced in the main land. Nearly all of them are still in operation as the household energy supply in some remote regions away from the grid. In 2008, the technological breakthroughs of wind turbine at the level of megawatt took place, the 235.3 MW wind turbines were installed, and demonstration wind farms were set up. In 2009, 341.8 MW wind turbines were installed, the wind power market was cultivated, and the construction of wind farms was accelerated. At the same time, the research on megawatt wind turbine was launched. After 2009, in 2010, there are 18 wind power plants having total 809.05 MW installed capacity and 424 wind turbines. After "The Renewable Energy Law of Turkey" was implemented in May 10, 2005, corresponding policies

Table 7
Wind power projects under operation in Turkey in 2010.

Location	Company	Installed capacity (MW)	Commissioning date	Turbin manufacturer	Turbine capacity (MW)	Number of WTGs
Osmaniye-Bahçe	Rotor A.Ş.	95.00	2010	GE	2.5	54
Manisa-Soma	Soma A.Ş.	49.50	2010	Enercon	0.9	55
Balıkesir-Bandırma	As Makinsan A.Ş.	24.00	2010	Nordex	3	10
Mersin-Mut	Akdeniz A.Ş.	33.00	2010	Vestas	3	11
Çanakkale-Bozcaada	Bores A.Ş.	10.20	2010	Enercon	0.6	17
İzmir-Aliağa	Bergama A.Ş	90.00	2010	Nordex	2.5	36
Edirne-Enez	Boreas A.Ş	15.00	2010	Nordex	2.5	6
Balıkesir-Havran	Alize A.Ş.	16.00	2010	Enercon	2.0	8
Manisa-Kırkağaç	Alize A.Ş.	25.60	2010	Enercon	0.8	32
Osmaniye-Bahçe	Rotor A.Ş.	45.00	2010	GE	2.5	18
Osmaniye-Bahçe	Rotor A.Ş.	60.00	2010	GE	2.5	24
Osmaniye-Bahçe	Rotor A.Ş.	50.00	2010	GE	2.5	20
Manisa-Soma	Soma A.Ş.	90.90	2010	Enercon	2, 0.9, 0.8	33 × 900 kW + 29 × 200 kW + 4 × 800 kW
İzmir-Aliağa	Doruk A.Ş.	30.00	2010	Enercon	2.0	15
Manisa-Soma	Bilgin A.Ş.	90.00	2010	Nordex	2.5	36
Hatay-Samandağ	Ziyaret A.Ş.	35.00	2010	GE	2.5	14
İzmir-Bergama	Ütopya A.Ş.	15.00	2010	GE	2.5	6
Balıkesir-Bandırma	Kapıdağ A.Ş	34.85	2010			
Total operating capacity		809.05				

came into effect one after another which led to a rapid development of the wind power market. Wind power projects under operation in Turkey are shown in Table 7 in 2010 [33,34].

To date, close to 3000 MW of Turkish wind power projects have been licensed by EMRA, out of which 822.90 MW were operational at the end of February 2010, and a further 490.4 MW are under construction.

Recent three years have seen the start of a wind energy boom in Turkey. Before 1 November 2007, Energy Market Regulatory Authority (EMRA) had received applications for more than 6300 MW worth of wind projects, more than half of which are still under evaluation today. In 2010, 809.05 MW of new wind power capacity were added in Turkey's installed capacity, bringing the total up to 1522.2 MW. In December 2010, according to the Turkish Wind Energy Association (TWEA), this installed capacity is targeted to reach to between 10,000 and 15,000 MW by 2020. Taking into account the projects currently under construction, it can be expected that some 500 MW of wind projects will be added in 2011. The values of installed wind energy capacity for different locations and many cities of Turkey in January 2011 and January 2012 are given in Table 8 [33,34]. According to Table 8, the largest installed capacity for wind power generations, of 150.00 MW, will be found on Kırşehir-Mucur, Turkey, in 2011. In Balıkesir-Bandırma, wind power plant follows Kırşehir-Mucur with 150.00 MW. Among the cities on these locations, Kepsut, Samandağı and Ezine will exhibit the highest levels of wind energy conversion power plant capacity in 2011. Among all of the locations of Turkey, İzmir location exhibits the largest amount of wind power use and the greatest installed wind power capacity. Wind energy conversion systems are one of the fastest growing energy sources in Turkey. This represents a yearly growth rate of 75%.

In Turkey, wind electricity conversion system was set up with a nominal 55 kW power in Çeşme. Then the larger scale wind electricity was set up in Germiyan in Ceşme, Turkey. The biggest available wind energy power plant in Turkey is the Baki (Balıkesir-Şamlı) with 90.00 MW power. It was constructed in 2008 and uses 30 turbines, and each turbine has 3000 kW power. The current production wind energy projects in Turkey 809.05 MW. This production will be 1503.35 MW with capacity under construction and the projects with a turbine supply contract at the end of 2010. The development of modern Turkish wind power engineering began

Table 8
Wind projects expected to start construction in 2011.

Location	Company	Installed capacity (MW)	Commissioning date	Turbin manufacturer	Turbine capacity (MW)	Number of WTGs
Aydın-Çine	Sabaş A.Ş.	24.00				
Hatay-Merkez	Bakras Lt. Şti.	15.30		Vestas		
İzmir-Aliağa	Kardemir Ltd. Şti.	12.50		Nordex	2.50	5
İzmir-Aliağa	Garet Enerji A.Ş.	10.00		GE	2.50	4
Çanakkale-Ezine	Garet Enerji A.Ş.	22.50		GE	2.50	11
Balıkesir-Bandırma	Galata Wind Ltd.Şti.	30.00				
Balıkesir-Bandırma	Galata Wind Ltd.Şti.	93.00		Vestas	3	31
Aydın-Söke	ABK Enrj. A.Ş.	30.00				
İzmir-Foça	Doğal Enrj. A.Ş.	30.00		Enercon	2.00	15
İzmir-Aliağa	Doğal Enrj. A.Ş.	30.00		Enercon	2.00	15
Balıkesir-Kepsut	Poyraz A.Ş.	54.90		Enercon	2, 0.9	27 × 2000 kW + 1 × 900 kW
Hatay-Samandağ	Ziyaret RES A.Ş.	22.50		GE	2.5	9
Hatay-Samandağ	Samandağ RES A.Ş.	35.00				
Çanakkale-Ezine	Enejisa A.Ş.	30.00		Siemens	2.30	13
Kırşehir-Mucur	Al-Yel Ltd.Şti.	150.00		Repower	3.37	44
İzmir-Karaburun	Ayen Enerji A.Ş.	30.75		Suzlon	2.10	15
İzmir-Seferhisar	Ayen Enerji A.Ş.	24.00		Suzlon	2.10	12
Total capacity expected to start construction in 2011		644.45				

from 2006 when the 20 wind turbines of 1500 kW each began to operate at Bandırma, Balıkesir. Then, the wind farm consisting of 1 turbine of 850 kW was constructed at Silivri, Istanbul in 2006, and the other wind farm with total-installed capacity of 39.2 MW started to operate in2007 at Ceşme, Izmir. In the same year, it was constructed three wind farm that they have total 56.10 MW at Akhisar, Intepe and Gelibolu, respectively. In 2008, seven wind power plants began to produce electrical energy with 287.1 MW power capacities. They are located in Samandağı, Sayalar, Aliaga, Gaziosmanpaşa, Catalca, Şamlı, and Datça, respectively. At the end of 2008, total-installed capacity was 433.35 MW in Turkey. This capacity reached 835.75 MW at the end of 2009 with seven wind power plants. In addition, wind installed capacity in Turkey reached to 1503.35 MW by the end of 2010. Following this, licenses are scheduled to be granted for 10,000 MW in the coming five years, 15,000 within 10 years and 20,000 MW in the long term.

11. Results and recommendations

In this study, assessments of the wind characteristics and wind power potential and wind energy conversion systems in Turkey for the year 2010 and 2011 were investigated. This research was conducted to show that wind power is one of the most important energy sources for Turkey. Turkey has a considerably high level of wind energy; resources that can be utilized to satisfy a part of the total energy demand in the country. The latest applications have shown that wind energy sources in Turkey are a promising alternative energy. Wind speed and energy maps of Turkey have been presented and the potential areas are identified with the emphasis on their significance. In general, potential wind energy areas in Turkey lie in northern parts and the north-western parts, at locations along the Aegean Sea and Marmara sea coast. Aegean, Marmara, South East Anatolia and East-Mediterranean regions of Turkey are generally seen as promising of higher wind power potential compared to other parts of Turkey. However, the most single locations are in the Gökçeada Island and Bandırma area, these are all along the sea coasts. Other potential areas are along the middle Black Sea region, eastern Mediterranean areas and south-eastern Anatolia region (Mardin and Siverek locations), among the inland areas, Diyarbakır in south-eastern Anatolia provides a significant potential area. Turkey, whose wind energy potential is abundant, should be given much more importance in meeting energy demands. In Turkey, the available wind energy power was 433.35 MW by the end of the year 2008; and it became1503.35 MW at the end of 2010. The strong development of wind energy in Turkey is expected to be continued in coming years. After all, it can be concluded that wind energy generation locations in Turkey are all at low altitudes.

Wind energy is a clean resource, emissions-free power generation technology, and it doesn't pollute the atmosphere like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind power also has a positive effect on the quality of the air that we breathe, and the combustion of fossil fuels also produces the gasses sulphur dioxide and nitrogen oxide, both serious sources of air pollution. Wind turbines do not produce atmospheric emissions that cause acid rain or greenhouse gasses. Wind energy is a domestic source of energy, produced in Turkey. Wind power will play a particularly important role in Turkey with plentiful of wind energy when the price of crude oil continues to increase in the future. The nation's wind supply is abundant, and cost less to be produced, because fossil fuels pollute environment badly and their sources are not limitless in Turkey. Presently, major share of electricity generation in Turkey is from hydraulic and from thermal. Renewable energy sources in Turkey are in abundance, which can fulfill the growing energy demand. The energy demand in Turkey is increasing rapidly, like other developing countries in the world. Continued population growth, and economic and technologic development are driving energy demand faster than Turkey can produce it. Energy is essential to the economic and social development and will improve the quality of living life in Turkey. During the last two decades, the wide expansion of industrial and residential areas has caused a high demand of electrical power. Because of technological and economical grooving factors, renewable energy sources do not have wide application either in Turkey or in the world at present.

References

[1] Duic N, Alves LM, Chen F, da Graca Carvalho M. Potential of Kyoto protocol clean development mechanism in transfer of clean energy technologies to small Island developing states: case study of Cape Verde. Renewable and Sustainable Energy Reviews 2003;7:83–98.

[2] İlkılıç C, Türkbay İ. Determination and utilization of wind energy potential for Turkey. Renewable and Sustainable Energy Reviews 2010;14:2202–7.

[3] Lund H. The Kyoto mechanisms and technological innovation. Energy 2006;31:2325–32.

[4] Gourieres DL. Wind power plants theory and design. Oxford: Pergamon Press; 1982.

[5] Ackermann T. Means to reduce CO_2-emissions in the Chinese electricity system, with special consideration to wind energy. Renewable Energy 1999;16:899–903.

[6] GWEO. Global wind energy outlook; 2006 [accessed 20.09.06] http://www.greenpeace.org/raw/content/international/press/reports/globalwindenergyoutlook.pdfS.

[7] Freris LL. Wind energy conversion systems. London: Prentice Hall International (UK) Ltd.; 1990.

[8] Durak M. 2009 Yılı Sonu İtibarı İle Dünya'da ve Ülkemizde Rüzgar Elektrik Santral (RES) Projelerinin Son Durumu. İstanbul: Türeb; 2010.

[9] Oğulata RT. Energy sector and wind energy potential in Turkey. Renewable and Sustainable Energy Reviews 2003;7:469–84.

[10] Balat H. Contribution of green energy sources to electrical power production of Turkey: a review. Renewable and Sustainable Energy Reviews 2008;12:1652–66.

[11] Hepbasli A, Ozgener O. A review on the development of wind energy in Turkey. Renewable Sustainable Energy Reviews 2004;8:257–76.

[12] Alboyaci B, Dursun B. Electricity restructuring in Turkey and the share of wind energy production. Renewable Energy 2008;33(2008):2499–505.

[13] Ozgür MA. Review of Turkey's renewable energy potential. Renewable Energy 2008;33:2345–56.

[14] Güneş ve Rüzgar Enerjisi. Devlet Meteoroloji İşleri Genel Müdürlüğü Araştırma ve Geliştirme Çalışmaları; 2009, http://www.meteor.gov.tr/webler/arge/argealt 25.htmS.

[15] EIE (General Directorate of Electrical Power Resources Administration). http://www.eie.gov.tr/turkce/YEK/ruzgar/RGI_AYLIK_HIZLAR.xlsS; 2001.

[16] http://www.eie.gov.tr/turkce/YEK/ruzgar/DUNYADA_RES_GUCU20090304.doc.

[17] Wind atlas of Turkey. Ankara: General Directorate of Electrical Power Resources Survey and Development Administration and State Meteorology Organization; June 2002 [in Turkish], 218 p.

[18] N. Akgün, Rüzgar Analizi ve Türkiye Rüzgar Atlasının Hazırlanması—III. Lodos, 4–14. Berger; 2003, 1997. www.bergey.com/primer.htmlS.

[19] Güneş ve Rüzgar Enerjisi. DevletMeteoroloji İşleri Genel Müdürlüğü Araştırma ve Geliştirme Çalışmaları; 2009, http://www.meteor.gov.tr/webler/arge/argealt 25.htmS.

[20] EIE (General Directorate of Electrical Power Resources Administration). http://www.eie.gov.tr/turkce/YEK/ruzgar/RGI_AYLIK_HIZLAR.xlsS; 2010.

[21] 2009 Yılı Sonu İtibarı İle Dünya'da ve Ülkemizde Rüzgar Elektrik Santral (RES) Projelerinin Son Durumu; 2010. www.tureb.com.tr.

[22] Özbırak R. Türkiye Cilt I. Ankara: Milli Eğitim Bakanlığı Yayınları; 1996.

[23] Türeb S. http://www.ruzgarenerjisibirligi.org.trS; 2009.

[24] TEİAŞ (Turkish Electricity Transmission Corporation). http://www.teias.gov.tr; 2010.

[25] Wind in power: 2009 Europe and statistics; February 2010. http://www.ewea.org/fileadmin/ewea_documents.

[26] World Energy Council Turkish National Committee (WECTNC). Energy report of Turkey in 2010; 2010. Ankara, Turkey.

[27] Rüzgar Enerjisi, Elektrik Işleri Etüt İdaresi Genel Müdürlüğü. Ankara. http://www.eie.gov.tr; 1986.

[28] Ilkılıç C, Aydın H, Behçet R. The current status of wind energy in Turkey and in the world. Energy Policy 2011;39:961–7.

[29] Hepbasli A, Ozdamar A, Ozalp N. Present status and potential of renewable energy sources in Turkey. Energy Sources 2001;23:631–48.

[30] Aras H. Wind energy status and its assessment in Turkey. Renewable Energy 2003;28:2213–20.

[31] http://www.ruzgarenerjisibirligi.org.tr/guncel/04-02-09-turkiyedeki-ruzgarsantraller.
[32] 5346 Nolu Yenilenebilir Enerji Kaynaklarının Elektrik Enerjisi Üretimi Amaçlı Kullanımına ilişkin kanun, 18.05.2005 tarih ve 25819 sayılı Resmi Gazete. http://www.mevzuat.adalet.gov.tr/html/1477.html.
[33] http://www.ruzgarenerjisibirligi.org.tr/guncel/04-02-10-turkiyedeki-ruzgarsantralleri.
[34] Turkish Wind Energy Association (TWEA). Wind power plants under operation in Turkey; 2010.